



Arizona Intelligent Vehicle Research Program - Phase One: 1997 - 2000

Final Report 473(1)

Prepared by:
Stephen R. Owen
Arizona Transportation Research Center
206 South 17th Avenue, MD 075R
Phoenix, Arizona 85007

February 2001

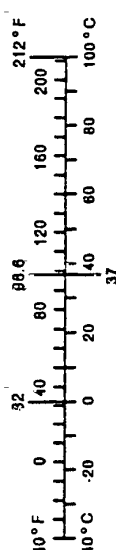
Prepared for:
Arizona Department of Transportation
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

The contents of the report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Arizona Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. Trade or manufacturers' names which may appear herein are cited only because they are considered essential to the objectives of the report. The U.S. Government and the State of Arizona do not endorse products or manufacturers.

Technical Report Documentation Page

1. Report No. FHWA-AZ-01-473(1)		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Arizona Intelligent Vehicle Research Program – Phase One: 1997 - 2000				5. Report Date February 2001	
				6. Performing Organization Code	
7. Author Stephen R. Owen, P.E.				8. Performing Organization Report No.	
9. Performing Organization Name and Address Arizona Transportation Research Center Arizona Department of Transportation Phoenix, Arizona				10. Work Unit No.	
				11. Contract or Grant No. SPR-PL-1(53)473	
12. Sponsoring Agency Name and Address ARIZONA DEPARTMENT OF TRANSPORTATION 206 S. 17 th Avenue PHOENIX, ARIZONA 85007 ADOT Project Manager: Stephen R. Owen, P.E.				13. Type of Report & Period Covered FINAL REPORT- PHASE ONE October 1997 to June 2000	
				14. Sponsoring Agency Code	
15. Supplementary Notes Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration					
16. Abstract – <p>This Phase One report documents a three-year research program by the Arizona Transportation Research Center to study possible practical applications of vehicle and infrastructure-based technologies. The project has reviewed, evaluated and demonstrated Intelligent Vehicle and Automated Highway System concepts that may improve the safety and efficiency of Arizona's highway system, particularly in winter maintenance operations.</p> <p>The key accomplishment of Phase One was to develop a research partnership with the California Department of Transportation (Caltrans) in their Advanced Snowplow (ASP) program. The Caltrans prototype plow, guided by discrete magnetic markers in the roadway, features lane position indication, lane departure warning, and a forward collision warning radar system. The ASP has been tested through two winters, 1998–99 and 1999–2000. Training and evaluations have been conducted at the California test facility on Interstate 80 near Donner Summit, and at a second dedicated test site on US 180 near Flagstaff, Arizona.</p> <p>This project report is presented in two sections. Section I gives a general history of the program, describing Arizona's interest and involvement in AHS and Intelligent Vehicle technologies through the summer of 2000. Section II of this report focuses in more detail on the Caltrans partnership, the site selection, the development of the magnet infrastructure in Arizona, and the initial two winters of testing and operational evaluation. The ADOT-Caltrans partnership, and the project, are ongoing in 2001 and 2002.</p>					
17. Key Words Intelligent Vehicles, Autonomous Vehicles, Driver Assistance, Winter Maintenance, Snowplows, ACMS, AVCSS, Human-Machine Interface, Lateral Guidance, Discrete Magnetic Markers		18. Distribution Statement Document is available through: ADOT Research Center (ATRC), 206 S. 17 TH Avenue (MD-075R) Phoenix Arizona, 85007		23. Registrant's Seal	
19. Security Classification Unclassified	20. Security Classification Unclassified	21. No. of Pages 136	22. Price		

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				APPROXIMATE CONVERSIONS TO SI UNITS			
Symbol	When You Know	Multiply By	To Find	Symbol	When You Know	Multiply By	To Find
LENGTH				LENGTH			
in	inches	2.54	centimeters	cm	millimeters	0.039	inches
ft	feet	0.3048	meters	m	meters	3.28	feet
yd	yards	0.914	meters	m	meters	1.09	yards
mi	miles	1.61	kilometers	km	kilometers	0.621	miles
AREA				AREA			
in ²	square inches	6.452	centimeters squared	cm ²	millimeters squared	0.0016	square inches
ft ²	square feet	0.0929	meters squared	m ²	meters squared	10.764	square feet
yd ²	square yards	0.836	meters squared	m ²	kilometers squared	0.39	square miles
mi ²	square miles	2.59	kilometers squared	km ²	hectares (10,000 m ²)	2.53	acres
ac	acres	0.395	hectares	ha			
MASS (weight)				MASS (weight)			
oz	ounces	28.35	grams	g	grams	0.0353	ounces
lb	pounds	0.454	kilograms	kg	kilograms	2.205	pounds
T	short tons (2000 lb)	0.907	megagrams	Mg	megagrams (1000 kg)	1.103	short tons
VOLUME				VOLUME			
fl oz	fluid ounces	29.57	milliliters	mL	milliliters	0.034	fluid ounces
gal	gallons	3.785	liters	L	liters	0.264	gallons
ft ³	cubic feet	0.0328	meters cubed	m ³	meters cubed	35.315	cubic feet
yd ³	cubic yards	0.765	meters cubed	m ³	meters cubed	1.308	cubic yards
Note: Volumes greater than 1000 L shall be shown in m ³ .				TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature
These factors conform to the requirement of FHWA Order 5180.1A							
*SI is the symbol for the International System of Measurements							

EXECUTIVE SUMMARY

This Phase One report documents the first three years of an ongoing research program by the Arizona Department of Transportation (ADOT) to study possible practical applications of vehicle and infrastructure-based Intelligent Transportation Systems technologies. The ATRC (Arizona Transportation Research Center) has performed this project as an internal research effort. During Phase One of this project, from 1997 to mid-2000, ADOT and the ATRC have reviewed, tested, evaluated and demonstrated Automated Highway System (AHS) and Intelligent Vehicle (IV) concepts. These new resources may improve the efficiency of Arizona's highway system, and in particular, may enhance the safety and efficiency of winter maintenance operations.



This project has focused on a study area that offers significant near-term benefits to transportation agencies. With an extensive rural highway network and only limited resources to keep the roads open in the worst weather conditions, Arizona faces major operational challenges. Snow removal and emergency response operations are among the most critical and hazardous duties for highway maintenance personnel. Safety and efficiency improvements are greatly needed in the winter maintenance field, and real gains can be achieved with ITS and IV concepts.

The key accomplishment of this project in Phase One has been to develop a working partnership between ADOT and the California Department of Transportation (Caltrans), whose Advanced Snowplow partnership offered significant opportunities for both states to benefit. The Caltrans-ADOT snowplow features lane position indication and lane departure warning, as well as a forward collision warning system. A continuous line of discrete magnetic markers embedded in the roadway provides guidance information to the snowplow.

This guidance system, installed on a Caltrans 10-wheel 10-yard plow, has been tested through two winters, 1998–99 and 1999-2000. Training and evaluation activities have been conducted both at the primary California project testbed on Interstate 80 near Donner Summit, and at a second dedicated test site on US Highway 180 near Flagstaff, Arizona.

This project report is organized into two distinct areas of research activity. Section One provides a general overview of the project's inspiration and goals, and it discusses the early IVI efforts in Arizona. It also describes the accomplishments of the program in terms of increasing the agency leadership's awareness of these concepts, and of the potential benefits from future research.

Section Two of this report describes in detail the more focused winter maintenance needs and goals that led to the long-term snowplow evaluation partnership between ADOT and Caltrans. This section discusses the specifics of site selection and construction of the Arizona intelligent infrastructure site. It also details the snowplow testing and evaluation program and the project's Phase One results, conclusions and recommendations for future research.

ACKNOWLEDGEMENTS – CHAMPIONS AND PARTNERS 1997 - 2000

ADOT's I-40 Corridor District Engineers, Maintenance Engineers & Superintendents:

- Flagstaff – Don Dorman, John Harper, Danny Russell
- Holbrook – Jeff Swan, Robert Wilbanks
- Kingman – Debra Brisk, Bill Wang, Larry Thomas

Flagstaff District Team Leaders:

- Joseph Chavez, Tom Durnez, Don Dodge, Tyrone Begishie

Caltrans Advanced Snowplow Project Development:

- Tom West, Greg Larson, Monika Kress, Mike Jenkinson, Kirk Hemstalk: California DOT
- Dr Ty A. Lasky, Dr. Bahram Ravani and the AHMCT project team.
- Dr. Wei-Bin Zhang, Dan Empey and the California PATH project team.

Project 473 Technical Advisory Committee:

During Phase One (1997-2000) the Research Project TAC represented the following ADOT sections and partner agencies; the complete list of TAC members is included as Appendix B.

- ADOT's I-40 Corridor Districts – Flagstaff, Holbrook, Kingman
- Arizona Department of Public Safety – Flagstaff DPS
- ADOT Transportation Technology Group (TTG)
- National Weather Service – Flagstaff -Bellemont
- ADOT Equipment Services
- Federal Highway Administration

The project also received very valuable support in the early activities from the ADOT Phoenix Maintenance and Construction Districts, and Jon Nelson of the VISION Field Office of the TTG.

TABLE OF CONTENTS

*** SECTION ONE – AUTOMATED HIGHWAY SYSTEMS FOR ARIZONA**

I.	INTRODUCTION	1
II.	STATEWIDE NEEDS AND NATIONWIDE SOLUTIONS.....	4
III.	THE SAN DIEGO TECHNICAL FEASIBILITY DEMONSTRATION	6
IV.	AUTOMATED HIGHWAY STUDIES IN ARIZONA	10
V.	ARIZONA MINI-DEMOS – SMART CARS / SMART HIGHWAYS	12
VI.	THE ARIZONA VISTA PROJECT	17
VII.	ADOT’s NATIONAL AND REGIONAL IVI ACTIVITIES.....	22

*** SECTION TWO - ARIZONA-CALIFORNIA SNOWPLOW RESEARCH**

VIII.	THE ARIZONA INTELLIGENT VEHICLE RESEARCH PROJECT.....	31
IX.	THE ADOT MAGNET-TESTING INITIATIVE	36
X.	TEST SITE REVIEW AND SELECTION – US 180 PROGRAM	42
XI.	US 180 TEST LANE MAGNET INSTALLATION	47
XII.	CALTRANS–ADOT ADVANCED SNOWPLOW OPERATIONS IN ARIZONA	57
XIII.	ARIZONA ASP-I RESEARCH ACTIVITY – MARCH 1999	59
XIV.	ASP-I RESULTS - WINTER 1998-1999.....	67
XV.	ARIZONA ASP-II RESEARCH ACTIVITY – FEBRUARY 2000	72
XVI.	ASP-II RESULTS – WINTER 1999-2000	80
XVII.	PHASE ONE RESEARCH SUMMARY – THE FIRST TWO YEARS.....	83

APPENDICES

A -	ORIGINAL RESEARCH PROBLEM STATEMENT	91
B -	TECHNICAL ADVISORY COMMITTEE – SPR 473	95
C -	JOINT PROJECT AGREEMENT JPA 98-222	97
D -	NAHSC-PATH-ADOT PUBLIC AHS DEMO– TEMPE ARIZONA– DEC 1997.....	102
E -	SUMMARY REPORT - SIX MAGNET TEST SITES – JULY 1998	107
F -	SUMMARY REPORT – US 180 MAGNET INSTALLATION – SEPT 1998	110
G -	OPERATOR INSTRUCTION SHEET - ASP-II - FEBRUARY 2000	113
H -	OPERATOR EVALUATION FORMS – ASP-I / ASP-II -	115
I -	DRAFT MEASURES OF EFFECTIVENESS FOR GUIDANCE SYSTEMS.....	119

LIST OF FIGURES

1. Winter Driving Hazards Threaten ADOT Crews and the Public.....	2
2. Demo '97 - Platoon Testing near San Diego on I-15.....	6
3. California PATH Fully-Automated Buick.....	7
4. Magnet Layout Activities at ASU Demo Site	13
5. Placing and Sealing Magnets with Hot Adhesive at ASU Stadium Demo Site	14
6. PATH Buicks at Arizona Demo – Sun Devil Stadium - December 15, 1997	15
7. The VISTA Prototype Vehicle	18
8. Demo of Autonomous Control of VISTA Car on April 28, 1999	20
9. Caltrans ASP-I Prototype Snowplow with Subsystems	34
10. California PATH Discrete Magnet Markers.....	36
11. Magnetic Marker Installation Requirements	37
12. PATH Magnet Test Sites - 1998	38
13. Test Magnet Installation at Seligman (I-40 MP 121.0)	39
14. Installing and Sealing Test Magnets on I-40	40
15. The 6 Month and 18 Month Test Results with 3M Loop Sealant	41
16. Map View to North - US 180 Across Kendrick Park	42
17. Total Snowfall in the Kendrick Park Region: 1909 – 1996	43
18. Accident Distribution by Conditions on US 180 - Kendrick Park Plow Route: Five Winters - October 1994 to May 1999	43
19. View South to San Francisco Peaks at Milepost 237	44
20. ADOT Snowplow on 8 Percent Grade at US 180 Milepost 238	45
21. Advanced Snowplow Test Site Map – US 180	46
22. ADOT Survey Team at MP 237	48
23. Caltrans Pneumatic Percussion Drill and ADOT Electric Core Drill	49
24. The Core Hole Layout Template and Drilling Process	50
25. Four Two-man Crews on the Drill Line	51
26. Setting and Sealing the PATH Magnets	52
27. Pneumatic Sealant Gun	54
28. Installing Magnets	56
29. Caltrans Advanced Snowplow ASP-I	59
30. ASP-I - Magnetometers and CWS Radar Antenna	60
31. The HMI Display – ASP-I Program	60
32. ASP-I Operational Evaluation - North End of US-180 Test Area	61
33. Caltrans ASP-I at the Kendrick Park Staging Area	62
34. Diagram of Single-Antenna CWS Radar Coverage on ASP-I	66
35. Mean Speed as a Function of Curve Radius	67
36. Key Subsystems – Second Winter - the Caltrans ASP-II Snowplow	72
37. ADOT Team Leaders Being Briefed on the New CWS Radar Equipment	74
38. Area of Coverage with Dual Radar Antennas	76
39. Revised HMI Screen Display for ASP-II	77
40. Sample of ADOT Operator Suggestions for ASP-II	78
41. Passenger –Side Secondary LCD Diagnostic Screen	79
42. Lateral Displacement by Road Segment – ASP-II on I-80 at Donner Summit	80

LIST OF TABLES

1. Test Site Diversity Guidelines 35

2. Evaluation Goals, Objectives, Measures of Effectiveness, and Potential Data Sources... 68

3. Summary of Snowplow Operator Responses to Interviews 69

PROJECT ACRONYMS AND ABBREVIATIONS

Acronym	Definition
ACMS	Advanced Construction and Maintenance Systems
ADOT	Arizona Department of Transportation
AHMCT	Advanced Highway Maintenance & Construction Technology (Research Center at UC Davis – Prime Contractor for ASP)
APS	Applied Physics Systems
ASP-I	Advanced Snowplow, Phase I (Caltrans)
ASP-II	Advanced Snowplow, Phase II (Caltrans)
ATRC	Arizona Transportation Research Center (at Phoenix)
AVCSS	Advanced Vehicle Control and Safety Systems
AWMT	Advanced Winter Maintenance Testbed (Caltrans I-80 Site)
Caltrans	California State Department of Transportation
CWS	Collision Warning System
DGPS	Differential Global Positioning System
DOT	Department of Transportation
EMI	Electromagnetic Interference
FLD	Front Lateral Displacement
GPS	Global Positioning System
HMI	Human-Machine Interface
HOV	High-Occupancy Vehicle
HUD	Head-Up Display
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
I-40	Interstate 40 (in Northern Arizona)
I-80	Interstate 80 (in Northern California)
ITS	Intelligent Transportation Systems
ITSA	Intelligent Transportation Society of America
IV	Intelligent Vehicle
IVI	Intelligent Vehicle Initiative
LCD	Liquid Crystal Display
LIDAR	Light Detecting and Ranging
MMW	Millimeter Wave
MOE	Measure of Effectiveness
MP	Milepost
MSU	Montana State University (at Bozeman)
NAHSC	National Automated Highway Systems Consortium
NAU	Northern Arizona University (at Flagstaff)
PATH	Partners for Advanced Transit and Highways (at UC – Berkeley)

Acronym	Definition
RF	Radio Frequency
RFI	Radio Frequency Interference
RPM	Raised Pavement Marker
RTOS	Real-Time Operating System
SBC	Single Board Computer
UCB	University of California at Berkeley
UCD	University of California at Davis
US 89	US Highway 89 (NE of Flagstaff AZ)
US 180	US Highway 180 (NW of Flagstaff AZ)
WTI	Western Transportation Institute (at Montana State University)
3M	The 3M Corporation (Minnesota)